

LARP IR Cryogenics: Inner Triplet Heat Transfer Studies

Roger Rabehl
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Introduction

A significant portion of the FY06 LARP Cryogenics effort has focused on analyzing cold mass and heat exchanger designs capable of removing the substantial heat loads expected to accompany the $10^{35}/\text{cm}^2\text{-s}$ LHC luminosity upgrade. These design studies have thus far concentrated on the non-IP end of the Q1 cold mass, where the dynamic heat loads are greatest – over 100 W/m. This document presents the results of expanding the study to calculate the temperature profile of the entire inner triplet, not just the Q1 non-IP end. Sizing of the pumping line is also addressed.

Inner Triplet Thermal Analysis

Heat Deposition Data

Figure 1 shows the calculated heat deposition profile for the upgraded inner triplet [1]. These data have been presented elsewhere [2] and are repeated here for reference. This profile is used as the basis for all analyses presented here.

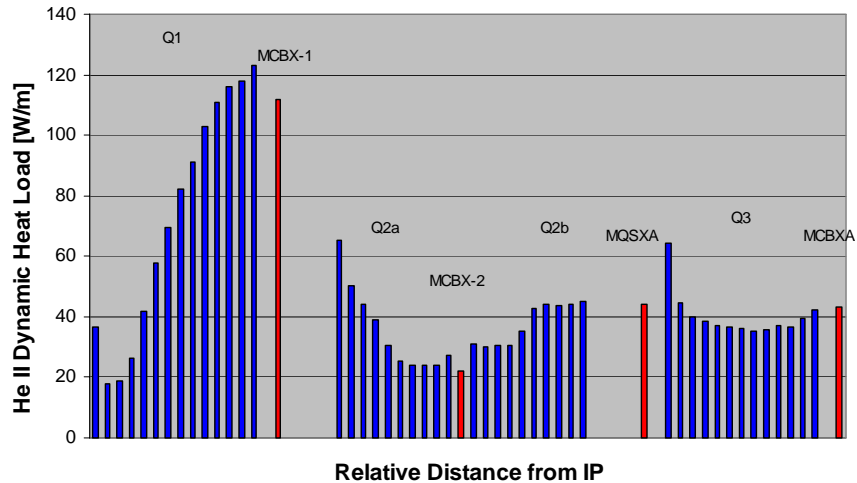


Figure 1 He II dynamic heat load vs. relative distance from the IP for an upgraded LHC IR, 90 mm quadrupoles with W-25 Re liners.

Cold mass parameters

Previous studies [2] have arrived at some parameters for the cold mass cooling system. These parameters, summarized in Table 1, were arrived at based on the Q1 non-IP end heat deposition rate and the inner triplet design temperature profile [3].

Table 1 Parameters of the cold mass cooling system.

Design parameter	Value
Beam pipe He II annular gap	1 mm
Collar radial cooling channels	7% open (effective)
Yoke radial cooling channels	5 mm wide
Yoke longitudinal cooling channels	400 cm ²
Crossover pipe	6 Sch 10 (6.357 in ID)

These design parameters, in conjunction with the dynamic heat load profile of Figure 1, allow a temperature profile of the four inner triplet cold masses to be calculated. Temperature profiles have been calculated for two scenarios: an external magnet heat exchanger, and multiple internal magnet heat exchangers.

External heat exchanger

The first scenario studied was for an external magnet heat exchanger. The geometry of an external heat exchanger has not been resolved, so the inner triplet temperature profile was calculated from the beam pipe annulus to the end domes of each cold mass. From the beam pipe annulus to the cold mass cooling holes, it is assumed that He II conduction is radial only. Longitudinal He II conduction then occurs in the cooling holes. A boundary condition of 2.00 K at the cold mass end domes is imposed as per the design temperature profile. The calculated temperature profiles for the inner triplet quadrupole cold masses are shown in Figure 2. The small discontinuity seen in the Q1 temperature curves is due to the magnet thermal center occurring between finite difference model nodes.

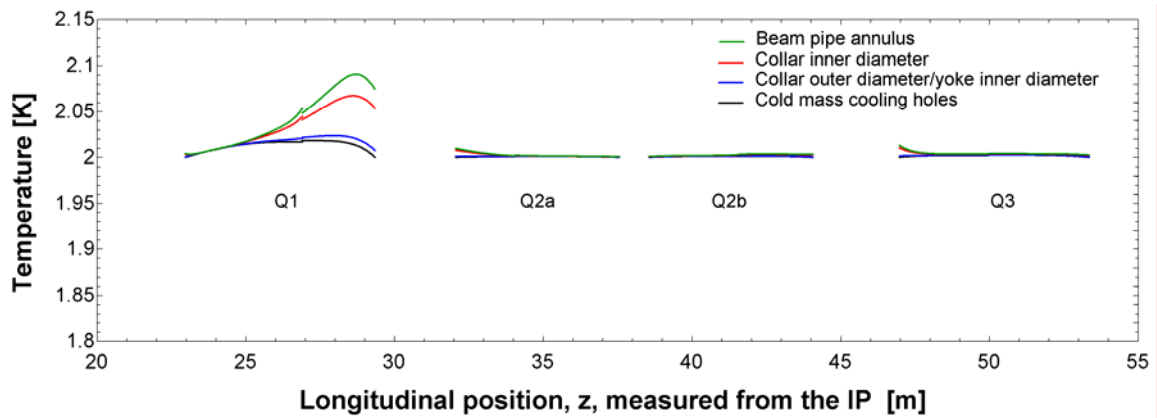


Figure 2 Calculated temperature profile for the inner triplet quadrupole cold masses with an external heat exchanger.

As expected, the Q1 cold mass shows the greatest temperature range. The beam pipe annulus reaches a maximum temperature of 2.09 K near the non-IP end.

Internal heat exchanger

The second scenario studied was for an internal magnet heat exchanger. This heat exchanger is envisioned as multiple tubes, partially filled with saturated He II, in the cold mass longitudinal cooling holes. A boundary condition of 1.826 K saturated He II in the heat exchanger is imposed as per the design temperature profile. The inside surface of each heat exchanger tube is assumed to be 40% wetted, and it is assumed there is sufficient remaining cross-sectional area of the cold mass longitudinal cooling holes so that the contained pressurized He II is isothermal. From the beam pipe annulus to the cold mass cooling holes, it is assumed that He II conduction is radial only. The calculated temperature profiles for the inner triplet quadrupole cold masses are shown in Figure 3.

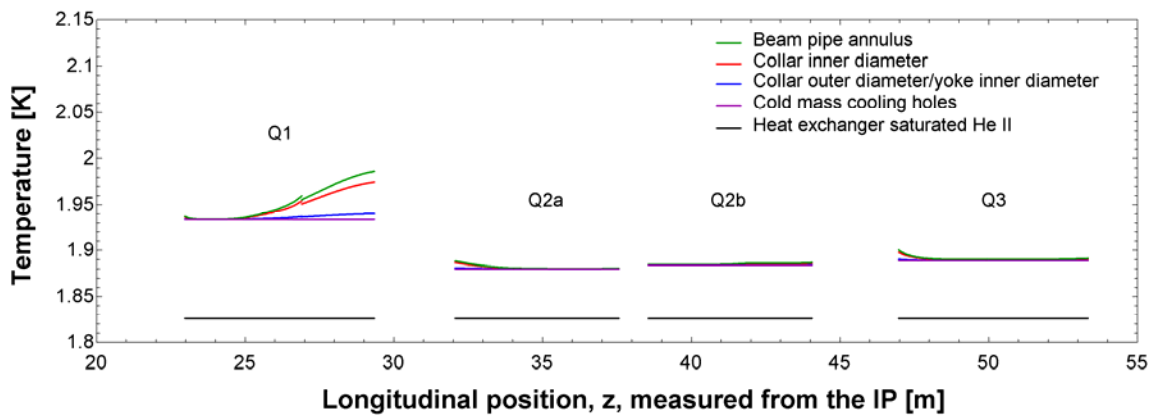


Figure 3 Calculated temperature profile for the inner triplet quadrupole cold masses with an internal heat exchanger.

The Q1 cold mass shows the greatest temperature range with the beam pipe annulus reaching a maximum temperature of just under 2.00 K near the non-IP end. In general, the inner triplet cold masses using internal heat exchangers remain significantly colder (about 100 mK) than the cold masses using external heat exchangers due to the shorter conduction path from the coils to the saturated He II in the heat exchanger.

Pumping Line Analysis

It is assumed that the upgraded triplet will use a dedicated pumping line as opposed to the integrated heat exchanger/pumping line in the existing triplet.

The design temperature profile specifies a pressure-induced equivalent temperature drop of 10 mK along the pumping line. Figure 4 shows the calculated pressure drop and equivalent temperature drop along the length of the pumping line as a function of the pumping line inner diameter. A 10% flashing loss and the use of a smooth (not corrugated) pumping line are assumed.

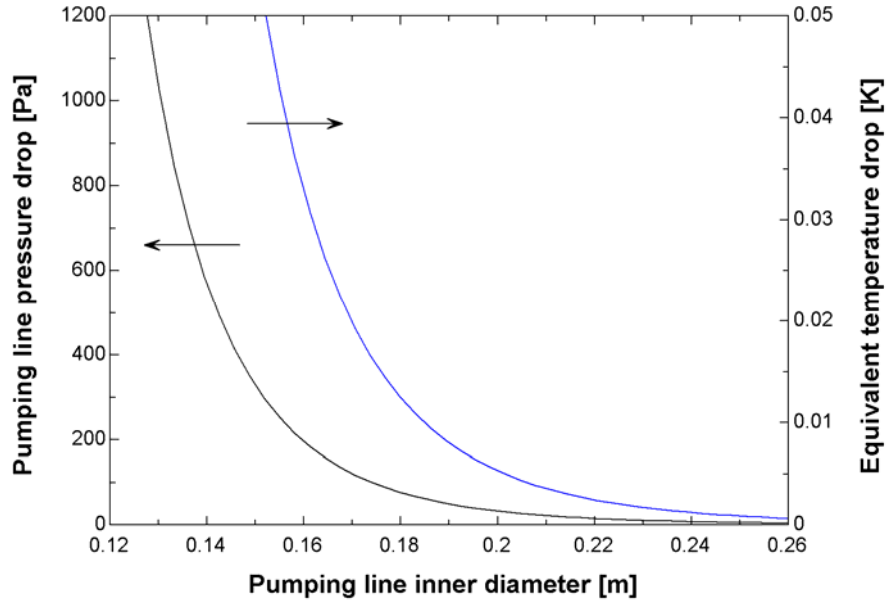


Figure 4 Pressure drop and equivalent temperature drop as a function of pumping line inner diameter.

In order to limit the equivalent temperature drop to 10 mK, a pumping line inner diameter of 185 mm (7.3 in) is required. For comparison, the inner diameter of the annular heat exchanger outer pipe in the existing triplet is 162.7 mm (6.4 in). Using this same size pipe in the upgraded triplet would result in a 29 mK equivalent temperature drop.

Conclusions

Inner triplet temperature profiles have been calculated for both external and internal heat exchangers. All magnet cold masses remain in He II for both cases with the Q1 reaching a maximum temperature of 2.0-2.1 K at the beam pipe of the non-IP end. Longitudinal temperature profiles of the Q2a, Q2b, and Q3 are very flat.

A pumping line inner diameter of 185 mm (7.3 in) is required to limit the pressure-induced equivalent temperature drop to 10 mK. This inner diameter is approximately 22 mm (0.87 in) larger than the inner diameter of the annular heat exchanger outer pipe in the existing triplet.

References

- [1] Nikolai Mokhov, FNAL.
- [2] R. Rabehl, "LARP IR Cryogenics: Parametric Studies of Heat Transfer in IR Quadrupole Magnets – Beam Pipe to External Heat Exchanger," LARP Document 279, May 2006.
- [3] R. Rabehl, "LARP IR Cryogenics Design Temperature Profile," LARP Document 100, version 2, March 2006.